

DOE Transmission Reliability Program Peer Review

WAMS Outreach Project: Sharing of Knowledge & Technology

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Prepared for the Transmission Reliability Program – 2004 Program Peer
Review, January 27-29, 2004, Washington, D.C.



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CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

Project: WAMS Outreach for Sharing of Knowledge & Technology

Objectives:

- 1. Expand the geographic reach of advanced wide area measurement systems (WAMS) to all regions of the North American interconnected grid.**
- 2. Facilitate extraction & use of WAMS information for management of power system reliability & performance.**
- 3. Facilitate development of technology, operational practices, and overall information infrastructure required by the objectives above.**



Project: WAMS Outreach for Sharing of Knowledge & Technology

Deliverables: (established prior to August 14 Blackout)

1. Assistance in WAMS startup operations
(technical advice, DOE/WAMS software, workshops)
2. Application of WAMS technologies
(system tests, disturbance analysis, methods development for grid reliability management)
3. Validation of system dynamic performance
(assessment of system behavior, comparisons against model results)
4. PMU evaluation & standards
(Applications, functional requirements, laboratory tests, field evaluation, dialog with developers of technology & standards)



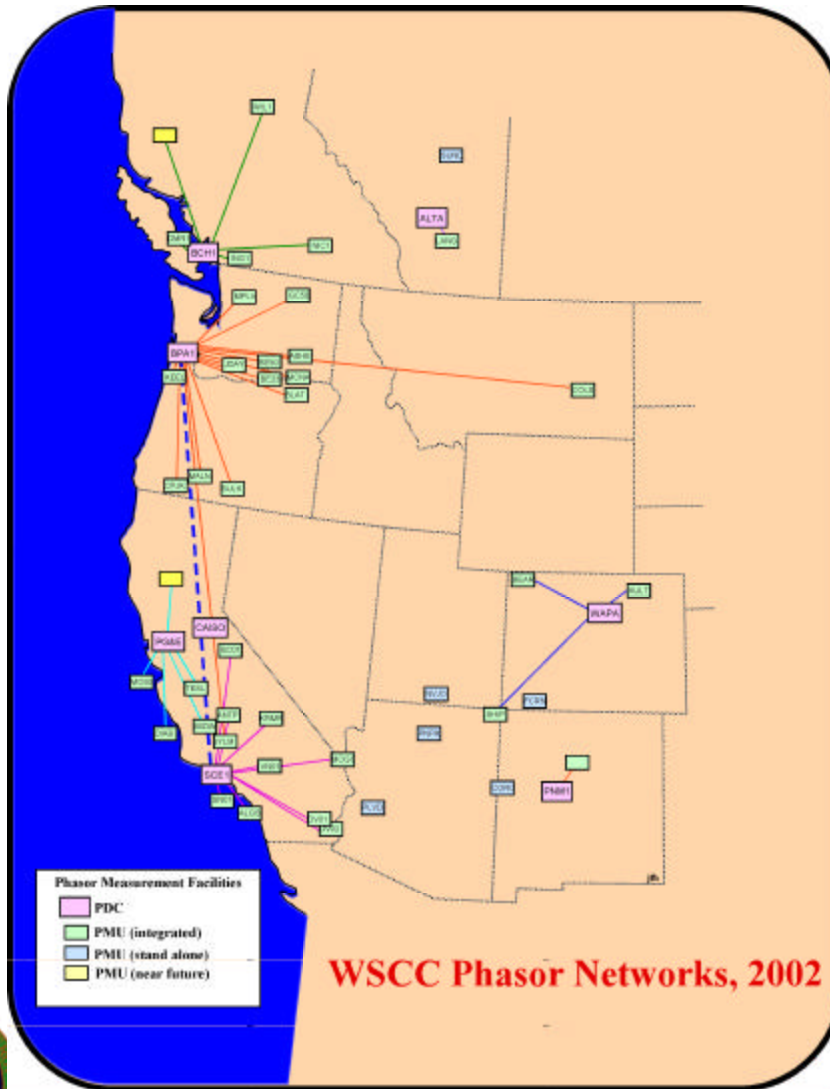
Project: WAMS Outreach for Sharing of Knowledge & Technology

Progress in FY03:

- 1. Extensive support to WECC technical groups in WAMS deployment, system tests, disturbance analysis, and model validation.**
- 2. Several training workshops within the WECC and the eastern interconnection.**
- 3. Extensive advice to developers and vendors of WAMS technology (see activity report for PMU testing).**
- 4. Assistance in data management & analysis for the U.S.-Canada Blackout of August 14, 2003.**
- 5. These contributions are reflected in about 40 working documents, including confidential reports and two IEEE publications on the August 14 Blackout.**



WSCC Monitor Facilities - 2003



Phasor measurement facilities:

- 8 PDCs (2 linked together)
- 40 integrated PMUs
- 7 stand-alone PMUs
- ~500 primary signals
- ~3.4 Mbytes per minute

PPSM units:

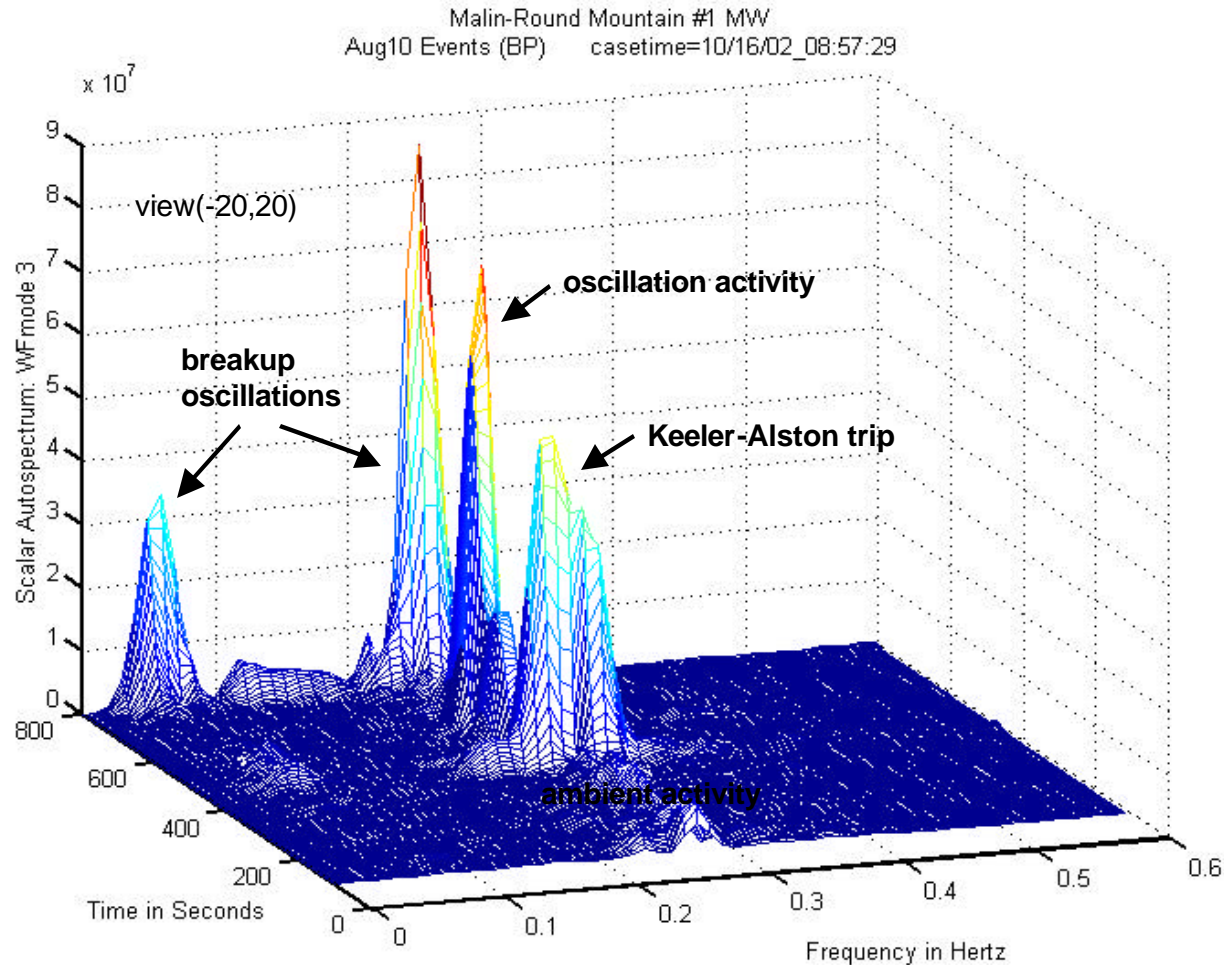
- ~20 units
- ~560 primary signals
- ~2.8 Mbytes per minute

Other monitors:

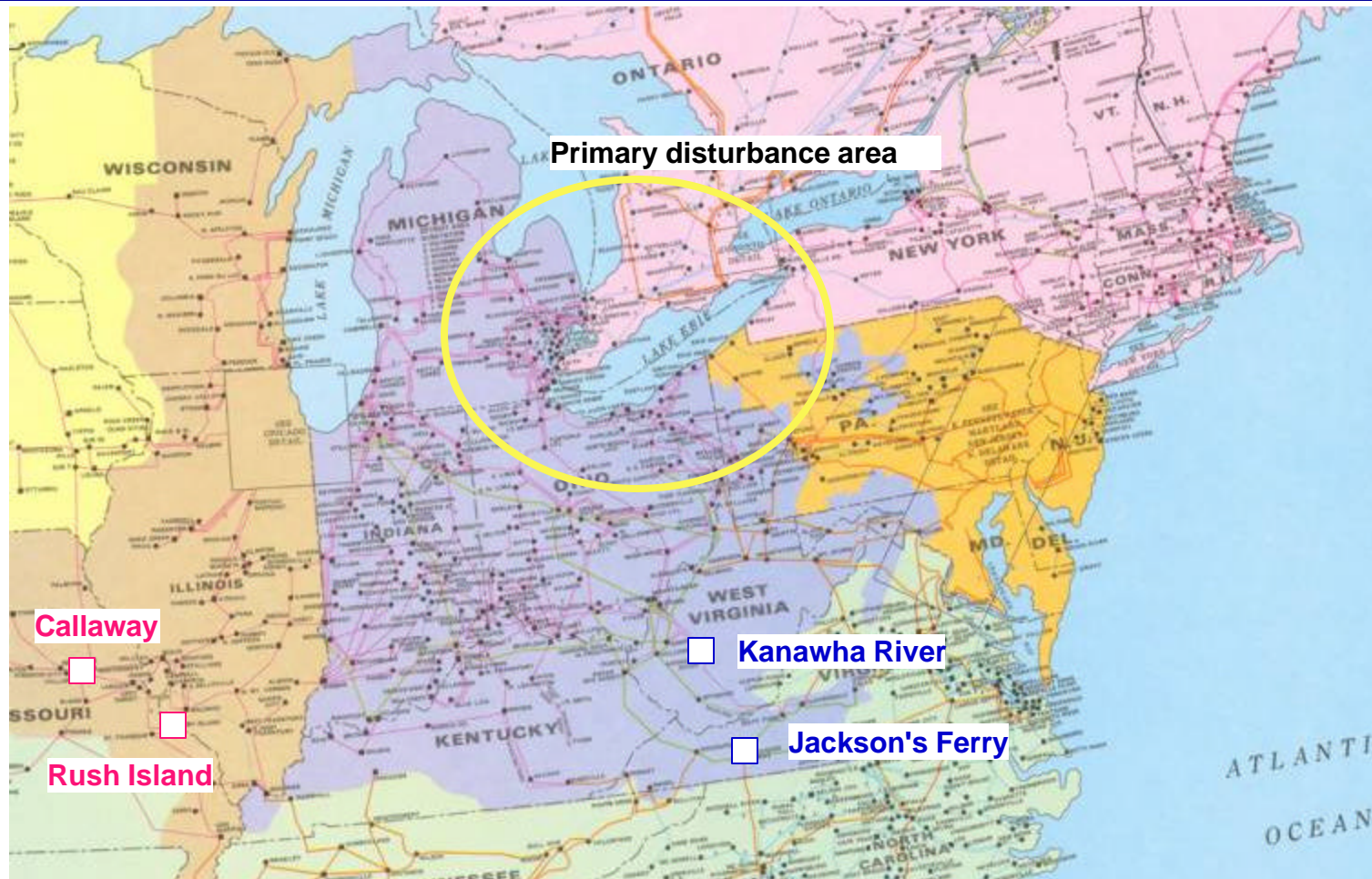
- ~10 units
- ~80 primary signals



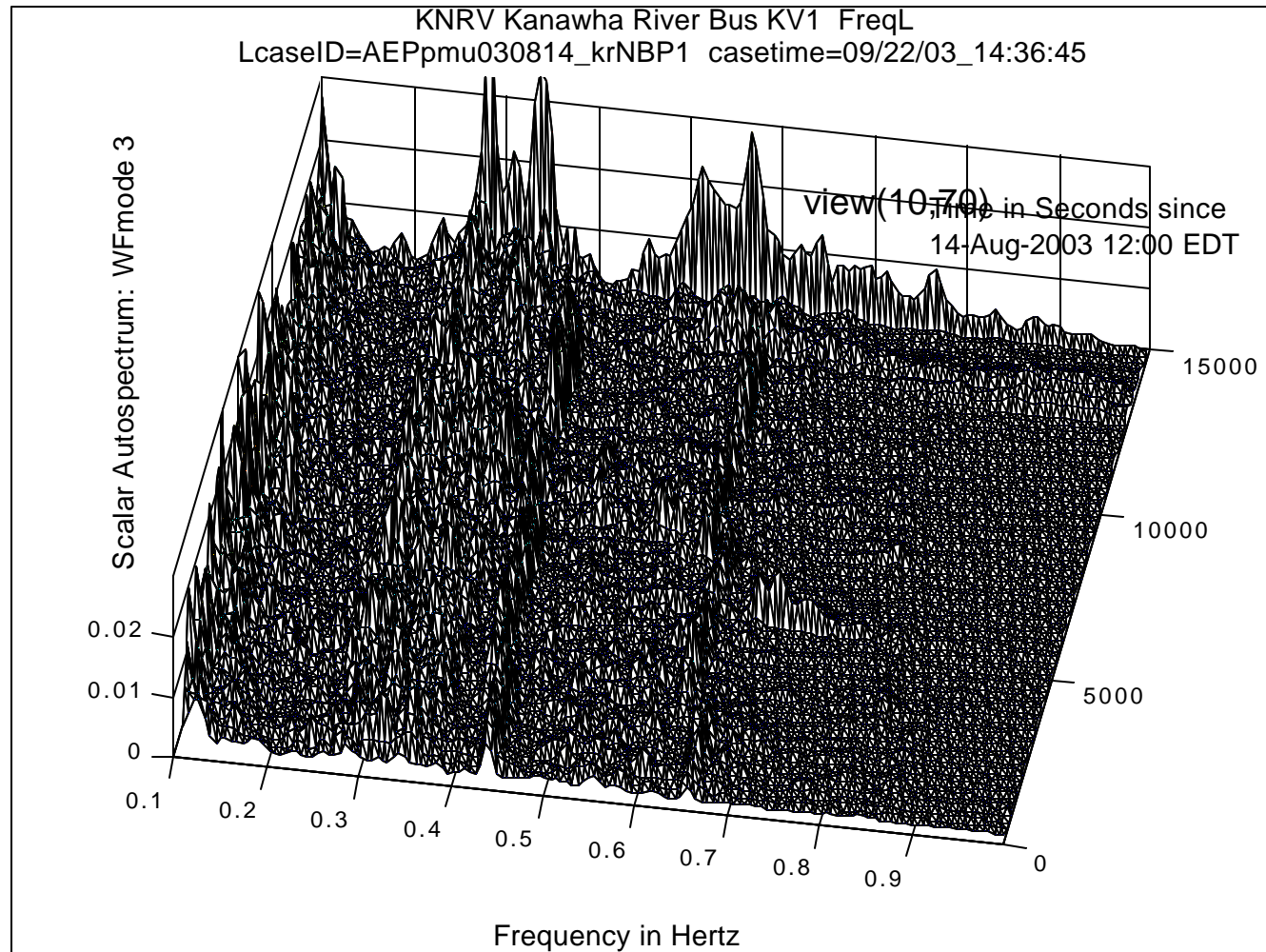
Waterfall Display of Dynamic Activity Just Before WSCC Breakup on August 10, 1996



AEP & Ameren PMUs on August 14, 2003



AEP Kanawha River bus frequency for Aug14 Blackout 12:00-16:10 EDT



Measurements Backbone for WAMS East on August 14, 2003 [1]

American Electric Power (AEP)

2 PMUs (Macrodyne 1690G), at 12 sps
Continuous recording to corporate server
software PDC based upon BPA/PNNL DSI tool box

Ameren

2 PMUs (ABB RES521), at 60 sps
Continuous recording to central PDC
BPA PDC [2]

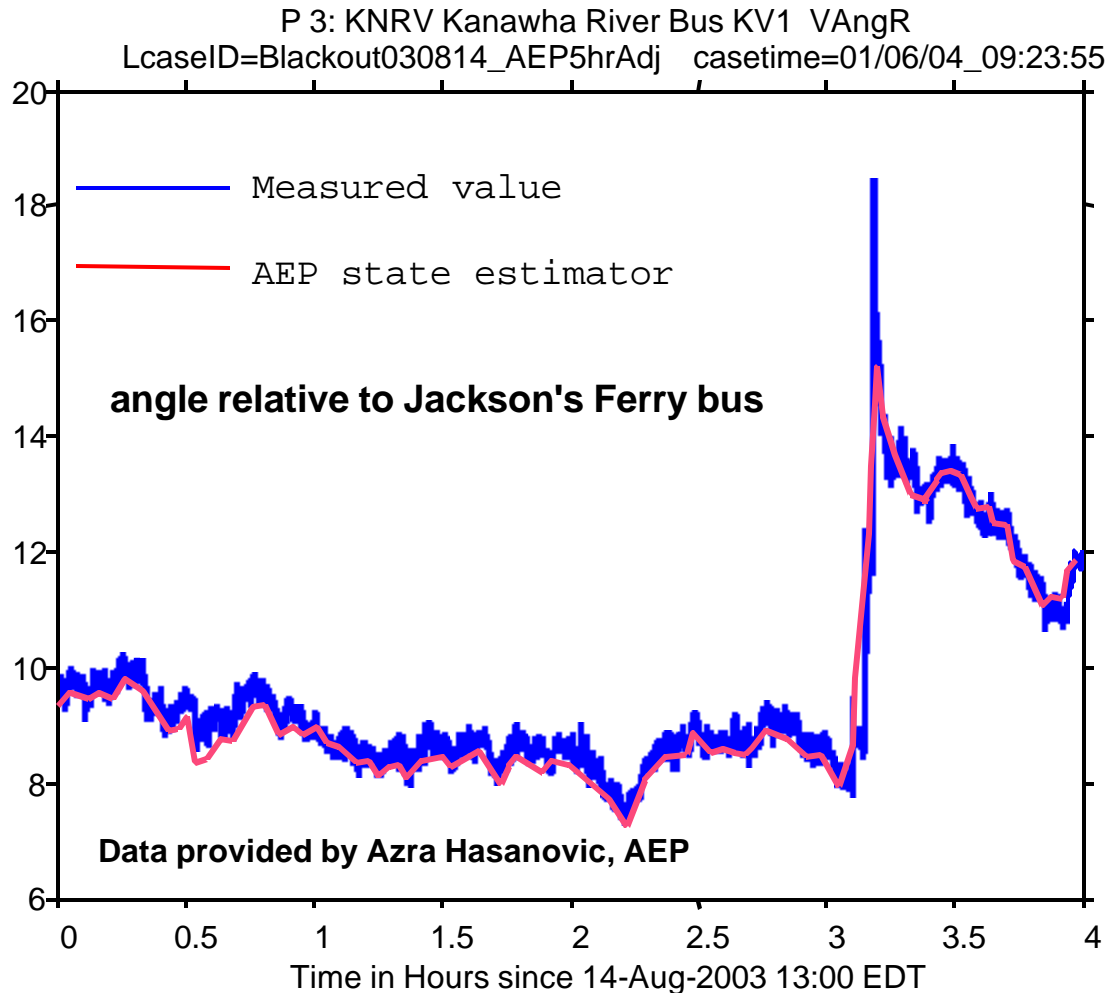
Entergy

3 PPSMs (BPA/PNNL), at 20 sps
Continuous local recording
periodically downloaded to central locations

- [1] **Performance of 'WAMS East' in Providing Dynamic Information for the North East Blackout of August 14, 2003**, J. F. Hauer, Navin Bhatt, Kirit Shah, and Sharma Kolluri. IEEE/PES Panel on Major Grid Blackouts of 2003 in North America and Europe, IEEE PES General Meeting, Denver, CO, June 6-12, 2004.
- [2] **Summary Description of the BPA Phasor Data Concentrator (PDC)**, K. E. Martin,. Internal Report of the Bonneville Power Administration, December 2003. Available: <ftp.bpa.gov/outgoing/WAMS%20Information/>



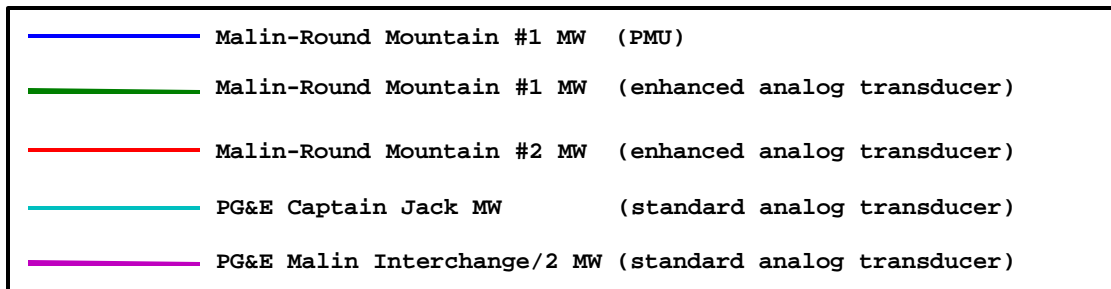
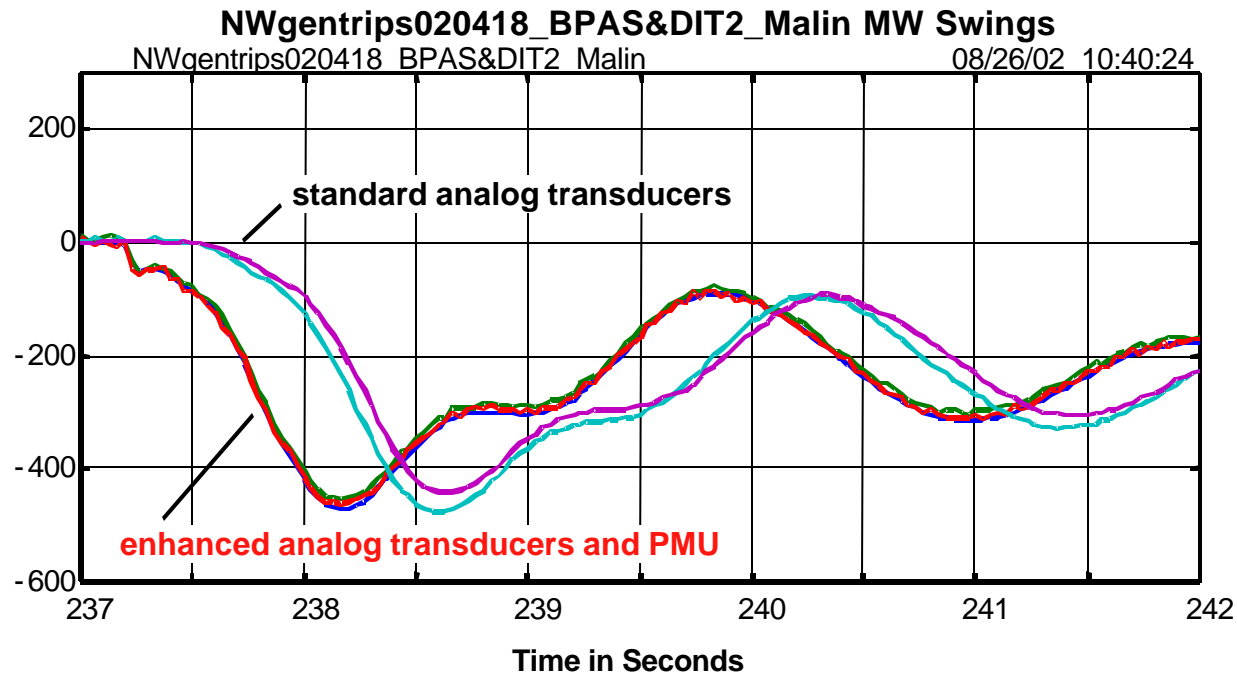
Measured vs. state estimator value of Kanawha River bus angle for U.S.-Canada Blackout on August 14, 2003



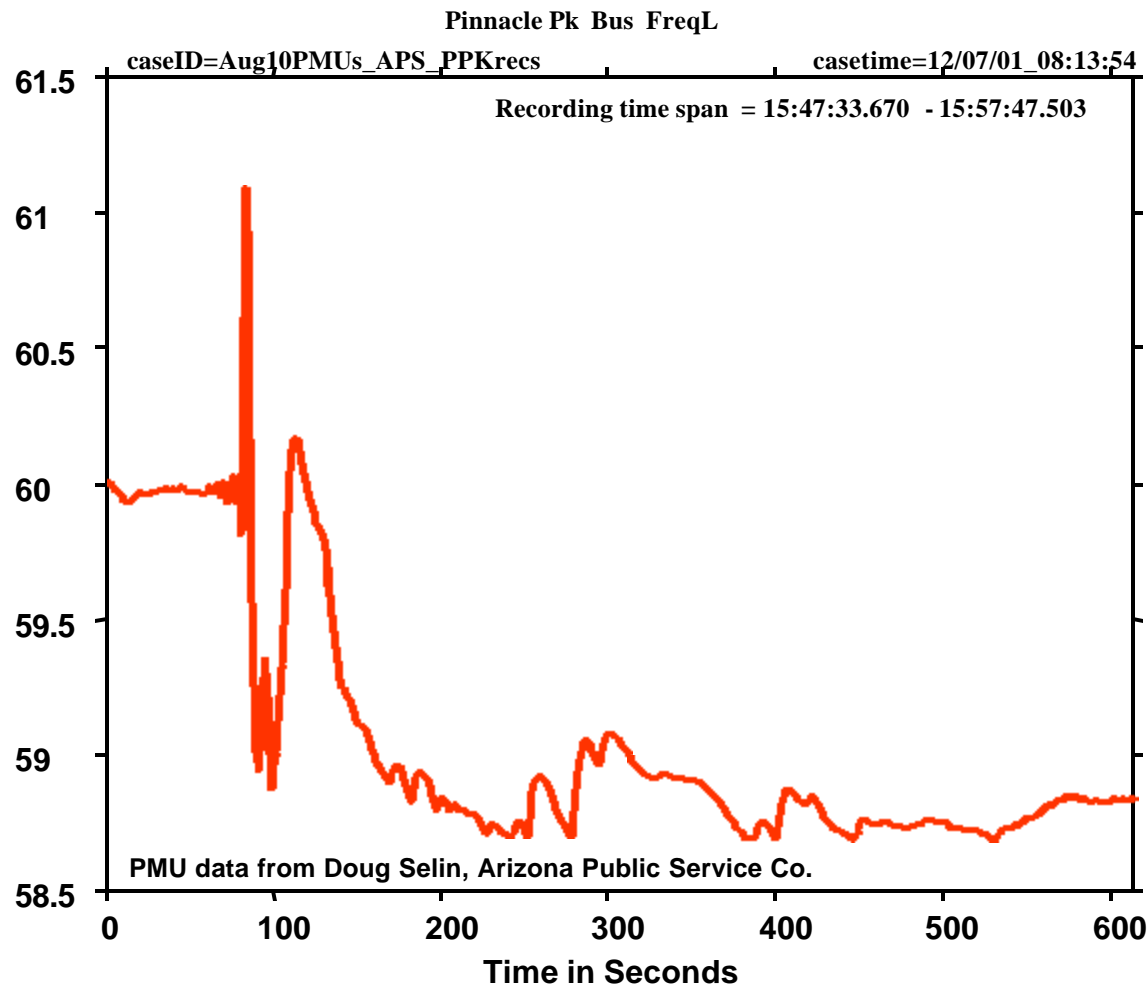
Evaluation of Phasor Technology



Inconsistent Signals for NW Generation Trip Event on April 18, 2002 (initial offsets removed)

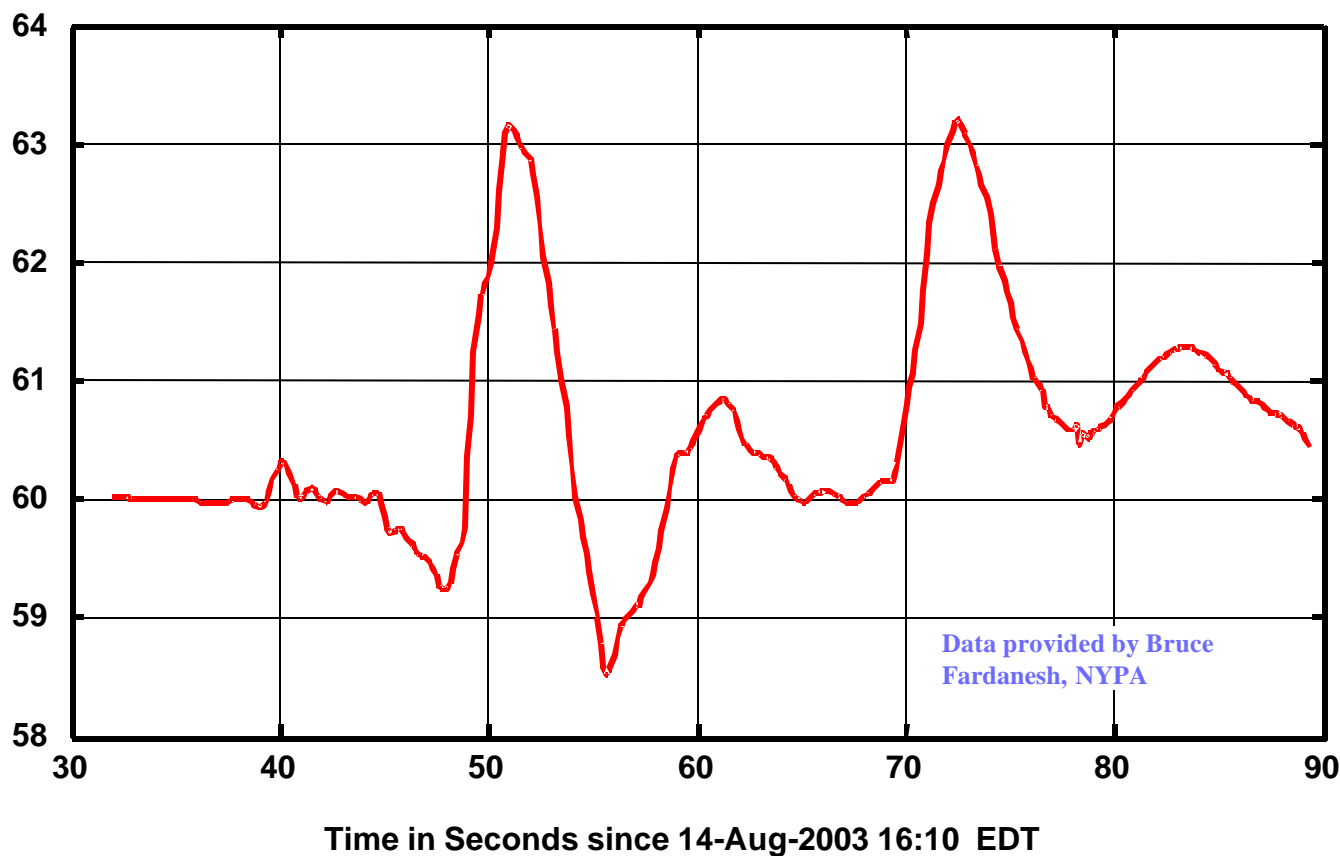


Challenge: Good measurements during protracted off-nominal frequency Western System Breakup on August 10, 1996

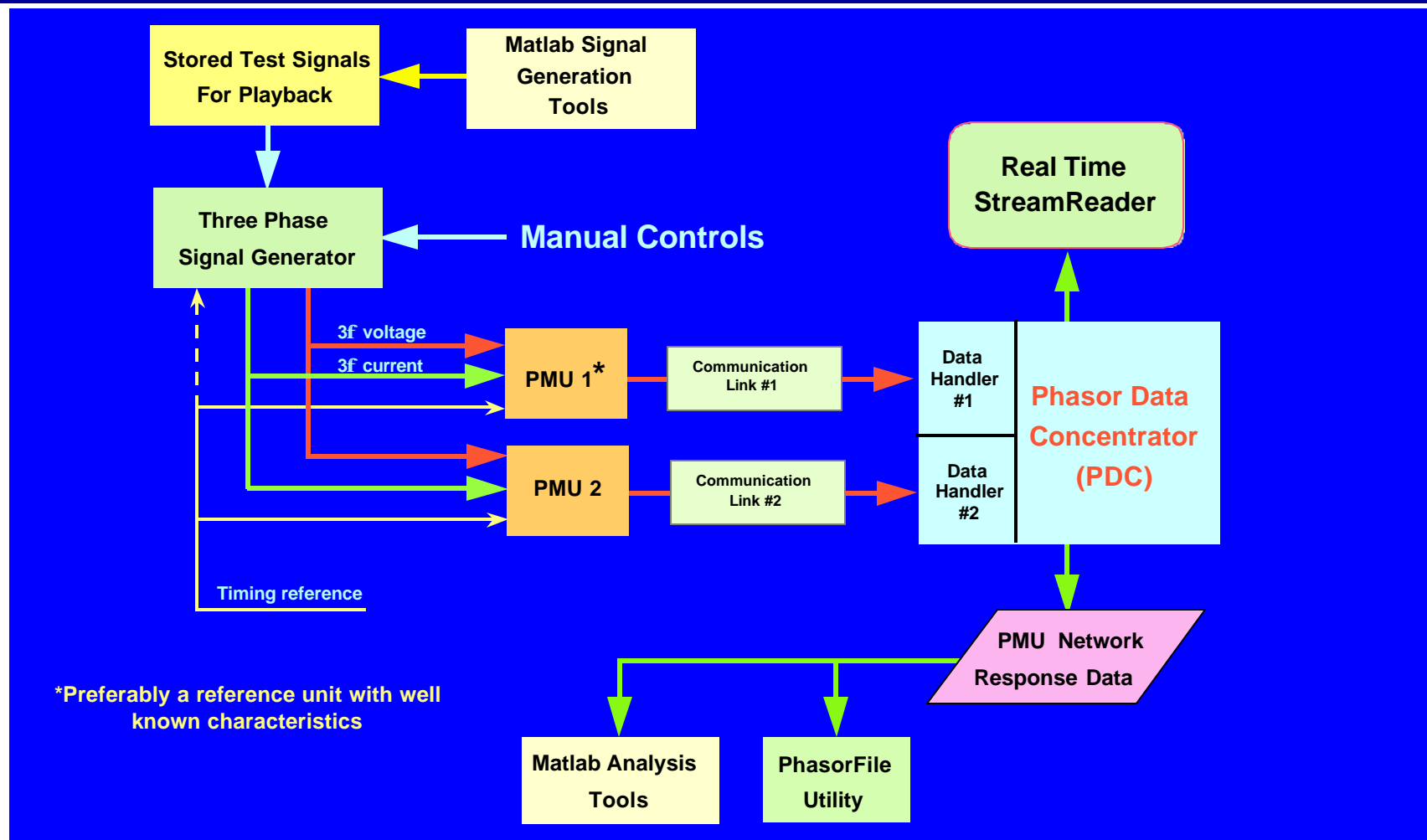


Challenge: Good measurements during protracted off-nominal frequency **U.S.-Canada Blackout on August 14, 2003**

Bus Frequencies Observed in New York Area for Aug14 Blackout



Geometry and Nomenclature for Laboratory Testing of Synchronized Phasor Networks



Laboratory Tests of PMU Performance

***(RESERVE SLIDES FOR TECHNICAL
QUESTIONS)***

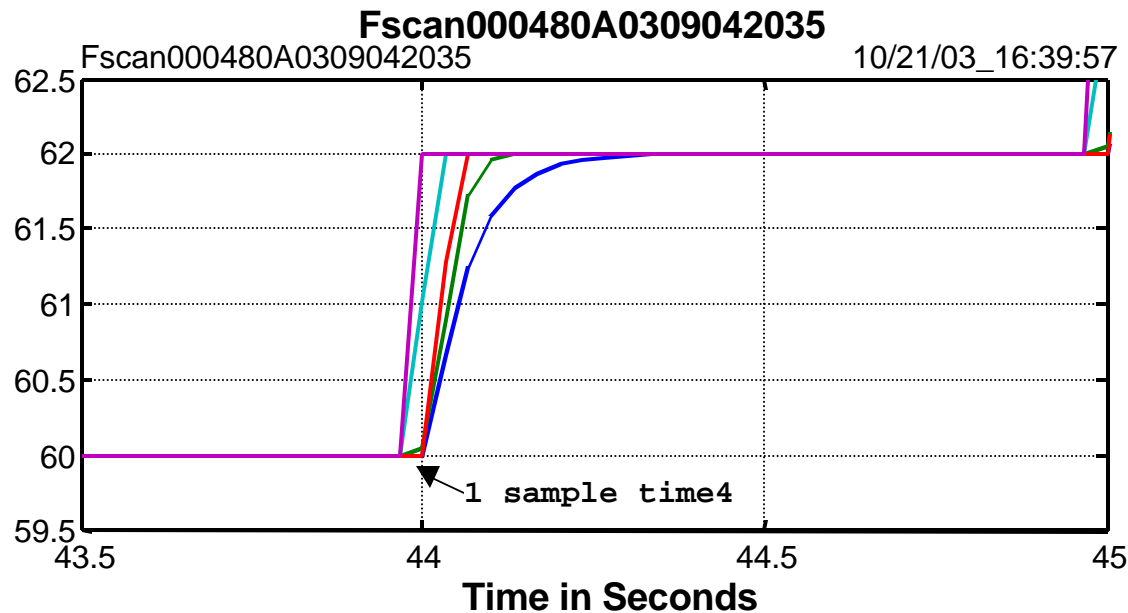


Desired Characteristics for Next Generation Transducers

- *High resolution & bandwidth, in control applications*
- *Rigorous protection against out-of-band input signals*
- *Absence of processing artifacts, such as spurious outputs*
- *Assured high accuracy, in metering applications*
- *Programmable outputs, for versatility of application*
- *Good networking options, both local and dial-in*
- *Option for synchronizing measurements against a precise external reference*
- *Overall affordability, considering all cost elements*



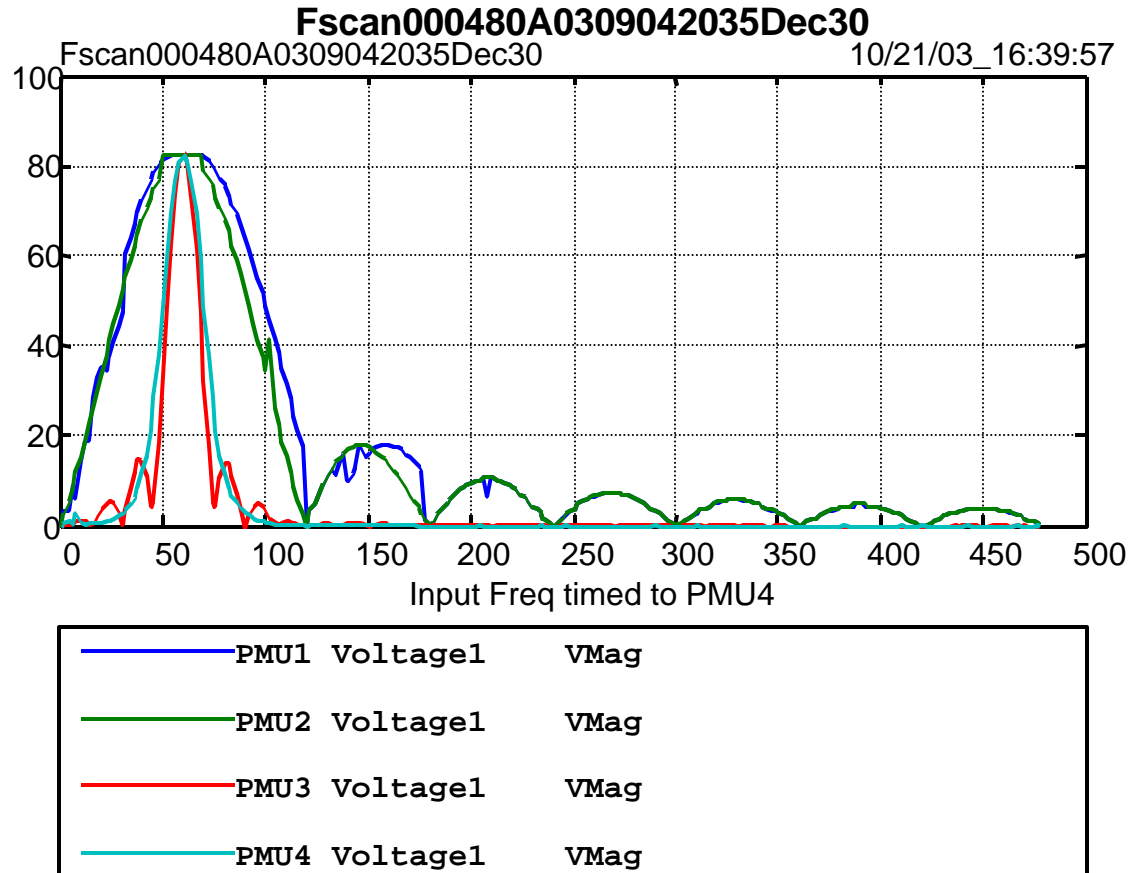
Measured Step Response of Four PMUs (Playback test file Fscan000480A)



PMU1 Voltage1	FreqL
PMU2 Voltage1	FreqL
PMU3 Voltage1	FreqL
PMU4 Voltage1	FreqL
Input Freq timed to PMU4	



Measured Filter Performance of Four PMUs (Playback test file Fscan000480A)



TEST: Modulation of Balanced 60.06 Hz carrier

TEST FILE: PMU_Mod6006MseriesB

Modulation frequencies are

[0 0.28 1.4 6.64 12.0 15.0 21.72 28.7 30.0 30.85 36.89 45.0] Hz

Dwell is adjusted to yield sufficient response data for each modulation frequency.

Note conspicuous aliasing near 30 Hz for PMU_Box4X30 (classical 4-cycle average). Exact frequencies and distortion components (if any) can be closely determined with Prony analysis.

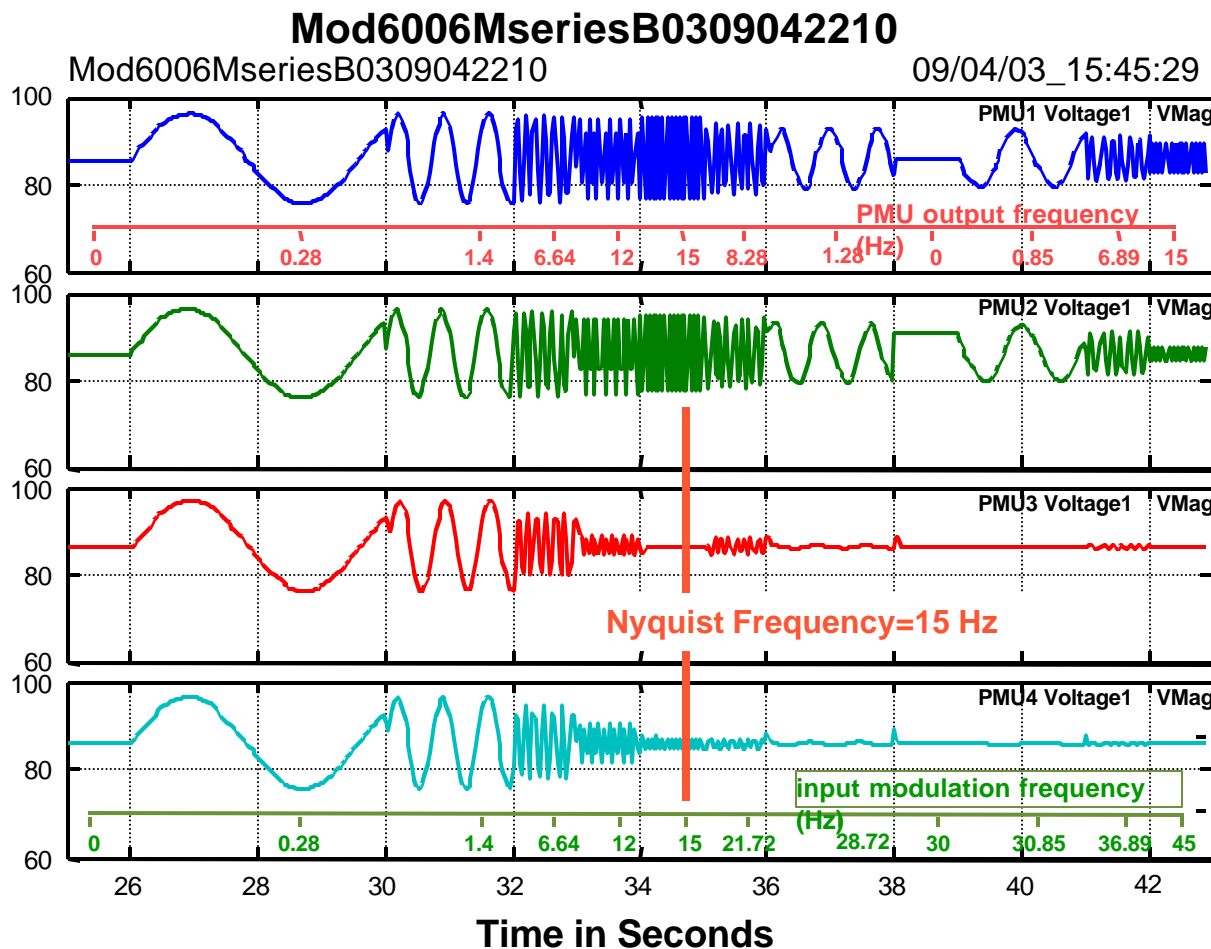
TEST ISSUES:

- a. Aliasing effects
- b. Modulation harmonics
- c. Noise levels



Frequency Aliasing in Four PMUs

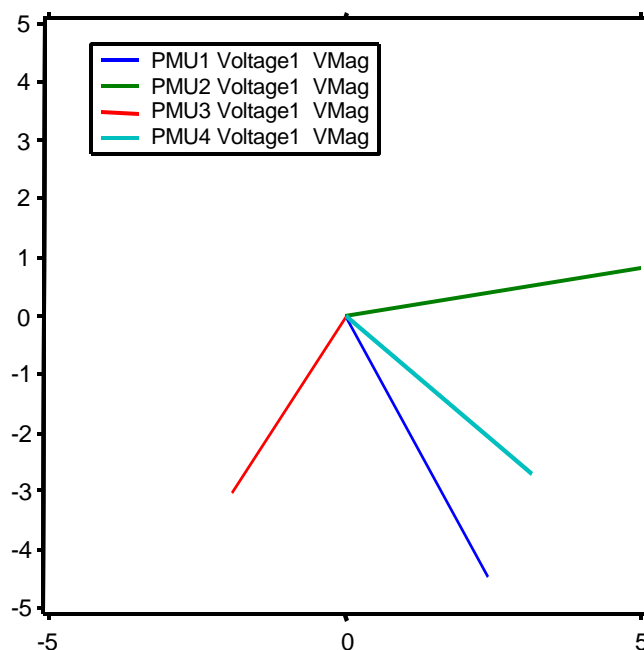
(Playback file Mod6006MseriesB)



Relative Timing among Four PMUs (Playback file Mod6006MseriesB)

Sorted PRS Table for pole1: TRange=[7.2667 8.0]+24.8 seconds

Signal	Freq in Hz	Damp Ratio (pu)	Res Mag	Res Angle	Rel delay (msec)
PMU1 Voltage1 VMag	6.64008767	0.00000005	10.10802100	-61.71652844	8.8
PMU2 Voltage1 VMag	6.64008767	0.00000005	10.11855742	9.44705084	-21.0
PMU3 Voltage1 VMag	6.64008767	0.00000005	7.20636136	-122.54655281	34.2
PMU4 Voltage1 VMag	6.64008767	0.00000005	8.29063475	-40.72127727	0.0



Scaled Compass Plot for mode 6.64008767 Hz

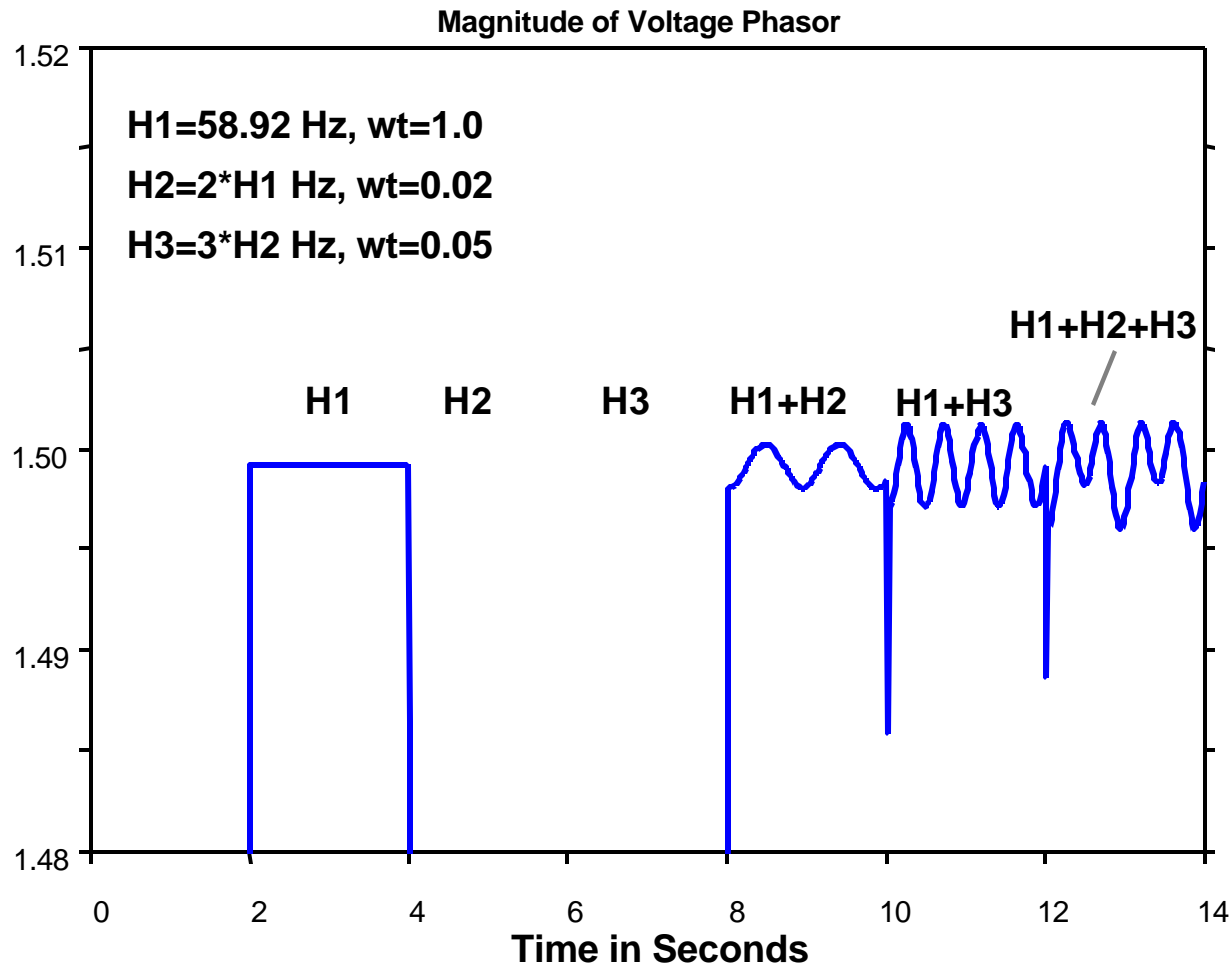


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DSItools Simulation, model PMU_Box1X60

Test file PMU_HarmTest5892B



Evaluating Phasor Network Performance Under Field Conditions

***(RESERVE SLIDES FOR TECHNICAL
QUESTIONS)***



Bus Angles from BPA State Estimator Compared Against PMU Measurements in BPA SCADA System

PHASE_ANGLE,RTNET[ONLINE] DNB:DJMG (C)					
PCPrint HAB App EMP App Navigate Related Displays					
Estimated / Measured Phase Angles					
REAL-TIME NETWORK					
RTNET			SCADA		
(Last RTRNET Run)			(Live Data)		
28-May-2003 16:04:20			28-May-2003 16:04:44		
NP01 GRAND COULEE - JOHN DAY	27.85	Deg.	COUL-JDAY_PANG	28.31	Deg.
NP02 GRAND COULEE - MALIN	49.02	Deg.	COUL-MALN_PANG	50.83	Deg.
NP03 JOHN DAY - MALIN	21.17	Deg.	JDAY-MALN_PANG	21.31	Deg.
NP06 GRAND COULEE - COLSTRIP	26.84	Deg.	COLS-COUL_PANG	28.91	Deg.
NP10 COLSTRIP - JOHN DAY	54.69	Deg.	COLS-JDAY_PANG	57.33	Deg.
NP11 GRAND COULEE - MAPLE VALLEY	26.08	Deg.	COUL-MPLV_PANG	26.41	Deg.
NP12 MAPLE VALLEY - KEELER	6.02	Deg.	MPLV-KEEL_PANG	5.80	Deg.
NP13 GRAND COULEE - BIG EDDY	30.10	Deg.	COUL-BIGE_PANG	31.62	Deg.
NP14 KEELER - BIG EDDY	2.00	Deg.	KEEL-BGED_PANG	1.60	Deg.
NP15 BIG EDDY - MALIN	18.92	Deg.	BIGE-MALN_PANG	18.01	Deg.
NP17 MALIN - VINCENT	21.02	Deg.	MALN-WINC_PANG	21.41	Deg.
NP16 BIG EDDY - EYLMAR	41.61	Deg.	BGED-EYLM_PANG	43.82	Deg.
NP18 JIN BRIDGER - IPC MIDPOINT	23.50	Deg.			
NP19 JIN BRIDGER - MALIN	27.93	Deg.			

Table provided by J. J. Graffy, BPA



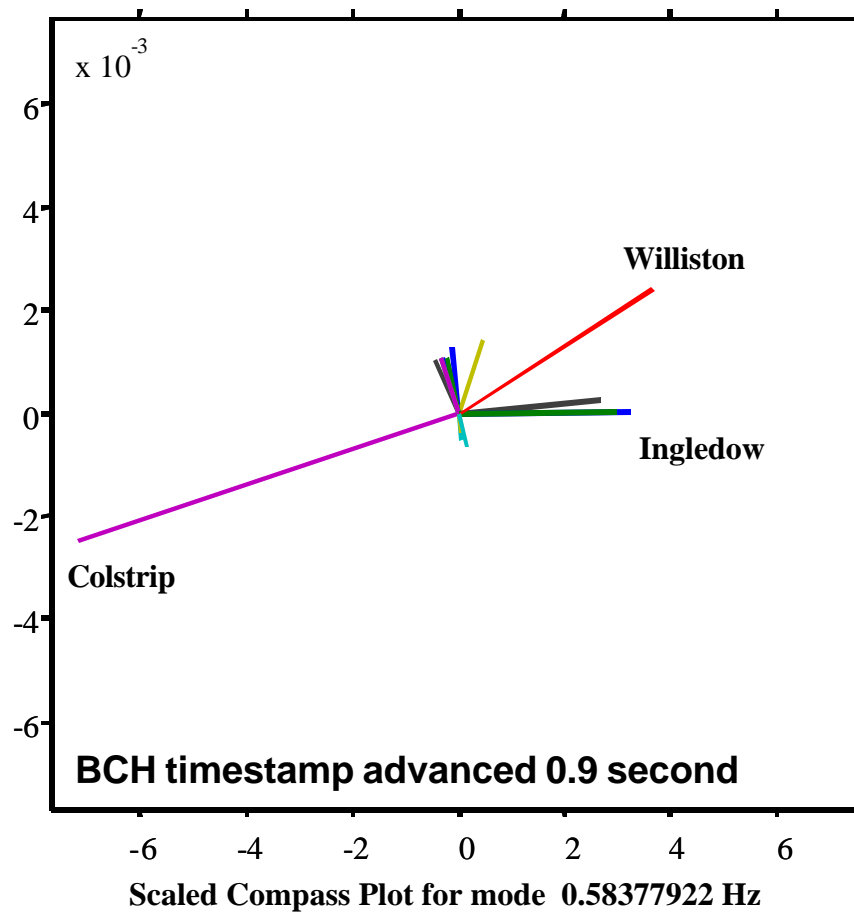
Bus Angles from BPA State Estimator Compared Against PMU Measurements in BPA SCADA System

OBSERVATIONS

- Coverage of state estimator & SCADA extend across more than 1000 miles, but bus angles are consistent within a few degrees.
- State estimators provide a useful means for checking a new PMU installation for local wiring errors, or for wiring changes that may be needed due to remote transpositions of transmission line conductors.
- Even a mature state estimator can gain value by the use of PMU data as an independent means to detect incorrect status information or processing errors.
- Direct incorporation of phase angle data into state estimator calculations seems especially promising for state estimators that draw upon sparse measurements, or that operate in very demanding information environments.

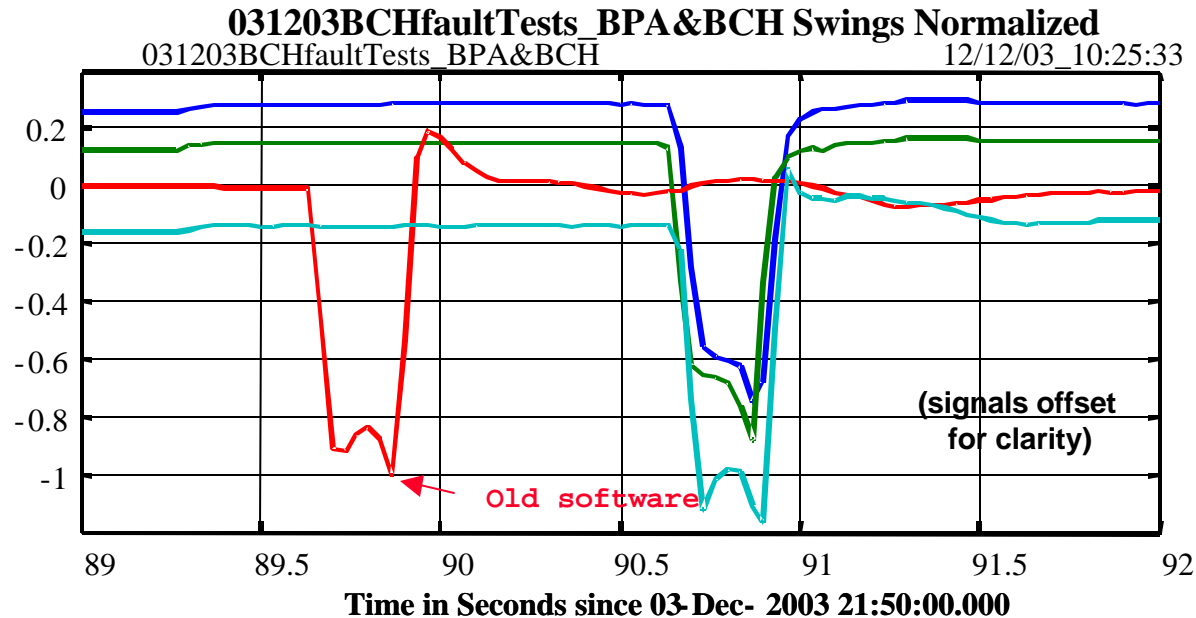


Modeshape Analysis to Determine Key Generators for Modeling & Control



Relative timing of VMag signals: BCH vs. BPA

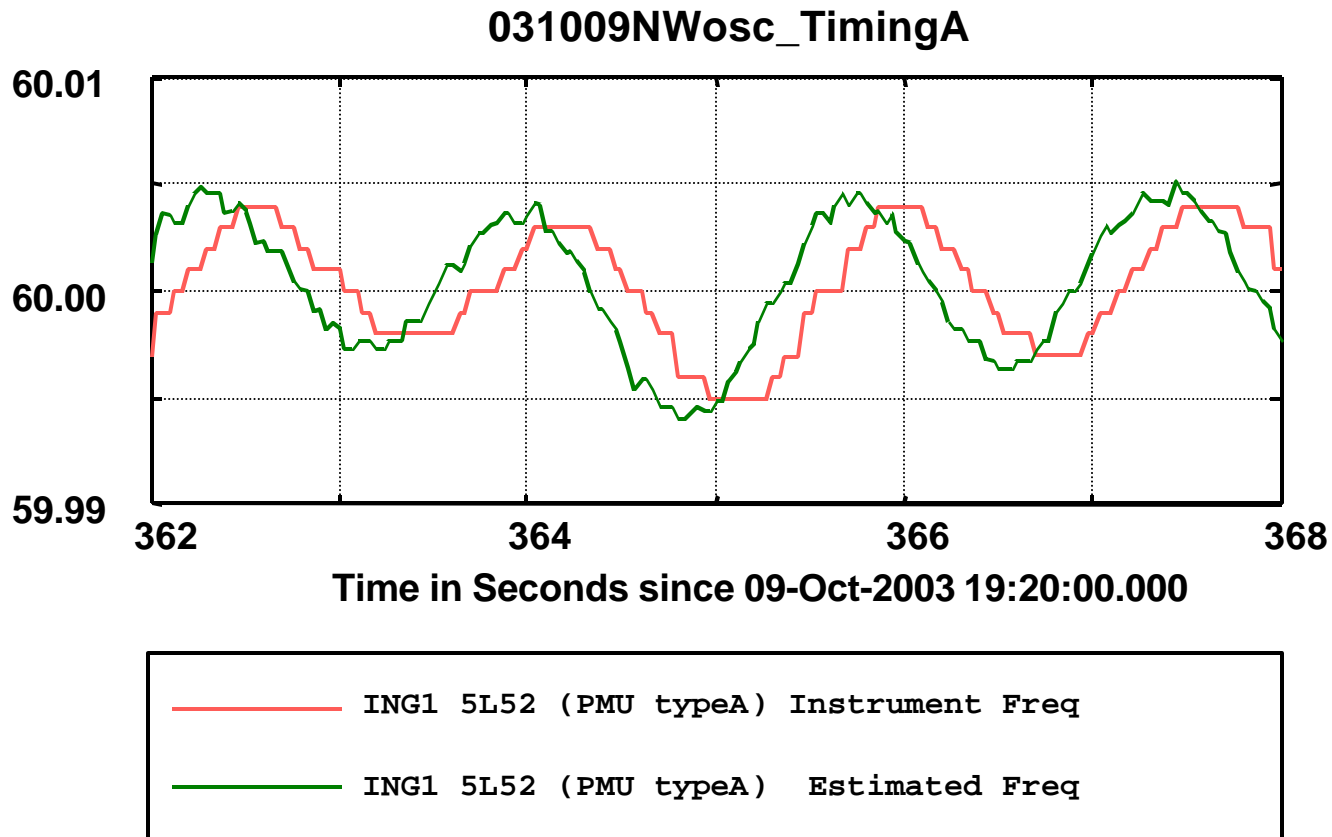
BCH fault test on December 3, 2003



- ING1 5L52 Voltage (PMU typeA, new software)
- ING2 5L52 Voltage (PMU typeB)
- SEL1 5L91 Voltage (PMU typeA, old software)
- MPLV Maple Voltage (PMU typeC)



Relative timing of PMU Frequency Signals WECC system event on October 9, 2003



Parasitic Voltage Oscillations in ING1 PMUA WECC system event on October 9, 2003

